Problem 05
Car

reporter:
Bárbara Cruvinel Santiago
Problem 05: Car

Build a model car powered by an engine using an elastic air-filled toy-balloon as the energy source. Determine how the distance travelled by the car depends on relevant parameters and maximize the efficiency of the car.
Contents

• Introduction
  – Definitions
  – Theory
  – Mathematical model

• Experiments
  – Experimental setup
  – Experimental results
  – Analysis
  – Comparison

• Conclusion
Introduction: Definitions

- **Car**: any object which moves over wheels without getting off of the floor or overturning, just using an internal independent source (air inside the balloon).

- **Efficiency**: ratio between useful energy and internal energy.

\[ \eta = \frac{E_{\text{out}}}{E_{\text{in}}} \]

- **Vehicle Autonomy**: distance per amount of air (combustible) – used as an indicator of efficiency.
Introduction: Forces acting over the car

• Gas force:
Introduction: Forces acting over the car

• Since then:

[Diagram of forces acting on a car]
Introduction: Forces acting over the car

- After the gas end:
Introduction: Gas propulsion force

• Variable force:
  – Mass;
  – Volume;
  – Moles;
  – Internal pressure.

• Influence of temperature and type of gas (saw in Clapeyron’s equation):

\[ PV = \frac{m}{M} RT \]
Introduction: Drag Force

\[ D = \frac{1}{2} \rho C_x A v^2 \]

- **Humidity**: alters the air density (almost irrelevant)
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Introduction: Friction

• We do not know if the friction is dynamic or static, as it would depend on the propulsion force.
Introduction: Flow

• Laminar:

• Turbulent:

• Laminar is better:
Introduction: Flow

(a) theory
(b) real

• The boundary layer breaks because of the pressure gradient.
Introduction: Rolling

• In order to improve the rolling, it is better to decrease the rolling between wheels and axis.
Introduction: Balloon elasticity

- Hooke’s Law:

\[ F = kx \]

Applicable to a narrow strip of the balloon.

- There’s a limit number of times to use the same balloon, as it loses the stiffness.
Experiment: Experimental description

- **Experiment 1**: aerodynamics test.
- **Experiment 2**: nozzle test.
- **Experiment 3**: propeller test.
- **Experiment 4**: chassis test.
- **Experiment 5**: surface test.
- **Experiment 6**: elasticity test.
- **Build the car based on the found parameters.**
  - Constant volume inside the balloon, as we pumped an air pump 70 times.
  - Inaccuracies: precision of the measuring tape (±0.05cm), of the caliper rule (±0.05mm) and of the scale (±0.1g).
Experiment: Material

- Geometric solids (cardboard and Styrofoam)
- Plastic wheels
- Slot car
- Wind tunnel (cardboard and fan)
- Digital chronometer
- Measuring tape
- Hair dryer
- Nozzles of different shapes (cardboard)
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Experiment: Material

- Caliper rule with precision of 0.05mm
- Paper (to make a straw)
- Air pump
- Elastic toy-balloon
- Corrugated fiberboard
- Adhesive tape
- Marbles
- String
- Scale with a precision of 0.1g
Experiment: Experiment 1 - aerodynamics test
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**Experiment: Experiment 1 - aerodynamics test**

### Theoretical drag coefficients

<table>
<thead>
<tr>
<th>Object</th>
<th>Drag Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Droplet</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Truck</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Sport car</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>Bike with cyclist</td>
<td>0.9</td>
</tr>
<tr>
<td>Semi-sphere (opened backwards)</td>
<td>0.38</td>
</tr>
<tr>
<td>Cube</td>
<td>1.05</td>
</tr>
<tr>
<td>Passenger car</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>Flat plate</td>
<td>1.2</td>
</tr>
<tr>
<td>Sphere</td>
<td>0.47</td>
</tr>
<tr>
<td>Motorcycle with a person</td>
<td>1.8</td>
</tr>
<tr>
<td>Bus</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Semi-sphere (opened forwards)</td>
<td>1.42</td>
</tr>
<tr>
<td>Cylinder</td>
<td>0.7-1.3</td>
</tr>
<tr>
<td>Section in C (opened forwards)</td>
<td>2.30</td>
</tr>
</tbody>
</table>

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Tehran, 22\textsuperscript{nd} – 31\textsuperscript{st} July, 2011
Experiment: Experiment 1 - aerodynamics test

Relative velocity between car and flow

- Droplet (vertex facing backward)
- Droplet (vertex facing forward)
- Sphere
- Cilinder
- Cone (vertex facing backward)
- Cone (vertex facing foward)
- Cube
- Parallelepiped
- Pyramid (vertex facing backward)
- Pyramid (vertex facing forward)

Relative velocity between car and flow (m/s)

- Possible error: lag time due to chronometer use (≈ 0.4s).
Experiment: Experiment 1 - aerodynamics test

• The experimental data agrees with theoretical coefficients.
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Experiment: Experiment 2 - nozzle test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building
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Experiment: Experiment 2 - nozzle test

![Bar chart showing force applied by the flow for different shapes]

- **Aerodynamics**
- **Nozzle**
- **Propeller**
- **Chassis**
- **Surface**
- **Elasticity**
- **Car building**
Experiment: Experiment 2 - nozzle test

Aerodynamics

Nozzle

Propeller

Chassis

Surface

Elasticity

Car building

Circular nozzle → Less regional turbulence → Better shape for nozzle
### Experiment: Experiment 3 - Propeller Test

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>Propeller</th>
<th>Chassis</th>
<th>Surface</th>
<th>Elasticity</th>
<th>Car building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Traveled Distance for Different Propellers (m)

<table>
<thead>
<tr>
<th></th>
<th>Without a straw</th>
<th>With a straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2.49</td>
<td>3.38</td>
</tr>
<tr>
<td>2nd</td>
<td>2.12</td>
<td>4.05</td>
</tr>
<tr>
<td>3rd</td>
<td>2.02</td>
<td>3.15</td>
</tr>
<tr>
<td>Average</td>
<td>2.21</td>
<td>3.53</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.25</td>
<td>0.47</td>
</tr>
</tbody>
</table>
Experiment: Experiment 3 - propeller test

- With a straw
- Flow is directed
- The flow tends to laminar
- The efficiency is increased
- Higher propulsion force
Experiment: Experiment 4 - chassis test

Aerodynamics
Nozzle
Propeller
Chassis
Surface
Elasticity
Car building
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Experiment: Experiment 4 - chassis test

<table>
<thead>
<tr>
<th>Chassis</th>
<th>Parallelepiped</th>
<th>Wedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2.39</td>
<td>0.41</td>
</tr>
<tr>
<td>2nd</td>
<td>1.89</td>
<td>0.35</td>
</tr>
<tr>
<td>3rd</td>
<td>2.01</td>
<td>0.39</td>
</tr>
<tr>
<td>Average</td>
<td>2.10</td>
<td>0.38</td>
</tr>
</tbody>
</table>

| Standard deviation | 0.26 | 0.03 |

- Even the wedge shape being more aerodynamic, its wheels showed to be worst, because of the friction.
Experiment: Experiment 5 - surface test

<table>
<thead>
<tr>
<th>Surface</th>
<th>Traveled distance for different surfaces (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With slots on the floor</td>
</tr>
<tr>
<td>1st</td>
<td>2.39</td>
</tr>
<tr>
<td>2nd</td>
<td>1.89</td>
</tr>
<tr>
<td>3rd</td>
<td>2.01</td>
</tr>
<tr>
<td>Average</td>
<td>2.10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Floor with slots

More uniform surface

Aerodynamics

Nozzle

Propeller

Chassis

Surface

Elasticity

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Experiment: Experiment 5 - surface test

Aerodynamics
Nozzle
Propeller
Chassis
Surface
Elasticity
Car building

More uniform surface → Less friction → Maximize the vehicle autonomy (and the efficiency)
Experiment: Experiment 6 - elasticity test

- Balloon 1: $k = 0.29\text{N/cm}$
- Balloon 2: $k = 0.38\text{N/cm}$
Experiment: Experiment 6 - elasticity test

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building

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nd – 31

st July, 2011
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Experiment: Experiment 6 - elasticity test

Maximum number of times that the same balloon can be used with similar results (vary maximum of 30cm):

• Balloon 1: 2 times.
• Balloon 2: 3 times.
## Experiment: Experiment 6 - elasticity test

<table>
<thead>
<tr>
<th>Aerodynamics</th>
<th>Traveled distance for different elasticities (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Balloon 1 (k=0.29)</td>
</tr>
<tr>
<td>Nozzle</td>
<td></td>
</tr>
<tr>
<td>Propeller</td>
<td></td>
</tr>
<tr>
<td>Chassis</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td></td>
</tr>
<tr>
<td>Elasticity</td>
<td></td>
</tr>
<tr>
<td>Car building</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Balloon 1</th>
<th>Balloon 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2.49</td>
<td>2.06</td>
</tr>
<tr>
<td>2nd</td>
<td>2.12</td>
<td>2.11</td>
</tr>
<tr>
<td>3rd</td>
<td>2.02</td>
<td>1.89</td>
</tr>
<tr>
<td>Average</td>
<td><strong>2.21</strong></td>
<td><strong>2.02</strong></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.25</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Experiment: Experiment 6 - elasticity test

- Stiffness should be increased
- Aerodynamics was worse for the stiffer
- Both cars showed basically the same efficiency
Experiment: Car building

- **Shape**: droplet
- **Nozzle**: circular
- **Chassis**: plastic wheels in a parallelepiped chassis
- **Propeller**: with a straw
Experiment: Built car video

- Aerodynamics
- Nozzle
- Propeller
- Chassis
- Surface
- Elasticity
- Car building
Conclusion

• **Most relevant parameters for the efficiency:**
  – Increase the driving force (gas propulsion);
  – Decrease the resisting forces;
  – Use the found relevant parameters to get this.

• **Features for the built car:**
  – Droplet shape (experiment 1);
  – Circular nozzle (experiment 2);
  – Paper straw as propeller (experiment 3);
  – Wheels with less friction (experiment 4);
References

10. JUNIOR, Prof. Dr. Guanis de Barros Vilela – Dinâmica dos fluidos
Acknowledgements

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Reynolds Number

\[ Re = \frac{\rho v D}{\mu} \]

Re = Reynolds Number (dimensionless)
\( \rho \) = fluid density (S.I.: Kg/m\(^3\))
D = diameter of the tube (S.I.: m)
\( \mu \) = dynamic viscosity of the fluid (S.I.: Pa.s)

- Re<2100: laminar flow
- Re>4000: turbulent flow
Drag coefficient for different shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>$C_D$ based on frontal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square cylinder:</td>
<td>2.1</td>
</tr>
<tr>
<td>Half-cylinder:</td>
<td>1.2</td>
</tr>
<tr>
<td>Half tube:</td>
<td>1.2</td>
</tr>
<tr>
<td>Equilateral triangle:</td>
<td>1.6</td>
</tr>
<tr>
<td>Hexagon:</td>
<td>2.3</td>
</tr>
<tr>
<td>Plate:</td>
<td>2.0</td>
</tr>
<tr>
<td>Thin plate normal to a wall:</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Drag coefficient for different shapes

<table>
<thead>
<tr>
<th>Shape</th>
<th>CD based on frontal area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rounded nose section:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L/H: 0.5</td>
</tr>
<tr>
<td></td>
<td>L/H: 1.0</td>
</tr>
<tr>
<td></td>
<td>L/H: 2.0</td>
</tr>
<tr>
<td></td>
<td>L/H: 4.0</td>
</tr>
<tr>
<td></td>
<td>L/H: 6.0</td>
</tr>
<tr>
<td><strong>Flat nose section:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L/H: 0.1</td>
</tr>
<tr>
<td></td>
<td>L/H: 0.4</td>
</tr>
<tr>
<td></td>
<td>L/H: 0.7</td>
</tr>
<tr>
<td></td>
<td>L/H: 1.2</td>
</tr>
<tr>
<td></td>
<td>L/H: 2.0</td>
</tr>
<tr>
<td><strong>Elliptical cylinder:</strong></td>
<td>Laminar</td>
</tr>
<tr>
<td>1:1</td>
<td>1.2</td>
</tr>
<tr>
<td>2:1</td>
<td>0.6</td>
</tr>
<tr>
<td>4:1</td>
<td>0.35</td>
</tr>
<tr>
<td>8:1</td>
<td>0.25</td>
</tr>
</tbody>
</table>
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Drag coefficient for different shapes

<table>
<thead>
<tr>
<th>Body</th>
<th>Ratio</th>
<th>$C_D$ based on frontal area</th>
<th>Body</th>
<th>Ratio</th>
<th>$C_D$ based on frontal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular plate:</td>
<td></td>
<td></td>
<td>Flat-faced cylinder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$h$</td>
<td></td>
<td></td>
<td>$L/d$</td>
<td>0.5</td>
<td>1.15</td>
</tr>
<tr>
<td>$b/h$</td>
<td>1</td>
<td>1.18</td>
<td>$L/d$</td>
<td>1</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.2</td>
<td></td>
<td>2</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.3</td>
<td></td>
<td>4</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.5</td>
<td></td>
<td>8</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>$\infty$</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipsoid:</td>
<td>$L/d$</td>
<td></td>
<td>Laminar</td>
<td>Turbulent</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td>0.27</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>2</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>4</td>
<td>0.2</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Drag coefficient for different shapes
Pressure gradient (boundary layer breaks)
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Golf ball case

- **Turbulent flow is better:**
  - Reduces the partial vacuum in the backside (existent with laminar flow);
  - Reattaches the boundary layer to the ball’s surface;
  - Drag force due to pressure is eliminated (just have the viscosity drag acting);
  - The rugosity induces the turbulent flow.
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Golf ball case

Laminar flow

Induced turbulent flow
Engine

- **Definition** *(Oxford Dictionary)*: “the part of a vehicle that produces power to make the vehicle move”.
- **Observation**: it doesn’t need to have mobile parts.
- **Example**: ramjet (use the air pressure for combustion and expulsion).